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An Annotated List of

Experiments in Physics

Used at the University of Cincinnati in the
Courses in Experimental Physics designed
for Sophomore Students of the
Academic and Engineering
Colleges.

COMPILED BY

James Edmund Ives,

Assistant Professor of Physics in the University of Cincinnati.

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PREFACE.

This is not intended to be a course in Experimental Physics, but, as its title implies, merely an annotated list of some 270 experiments, any one of which might be profitably performed by a sophomore student in college. As a rule no attempt has been made to describe the experiment, but a reference has been given to a full description of it in a standard manual or text book.

In the references, for the sake of brevity, the name of the author has been given without the title of the work. Below, therefore, is a list of the books referred to with their publishers:

Ames and Bliss, Experiments in Physics, Harper & Brothers, 1898.
Barker, Physics, second edition, Henry Holt & Co.
Ganot's Physics, translated by Atkinson, fifteenth edition, Wm. Wood & Co.
Glazebrook and Shaw, Practical Physics, fourth edition, Longmans, Green & Co.
Hastings and Beach, General Physics, Ginn & Co., 1903.
Henderson, Practical Electricity and Magnetism, new edition, Longmans, Green & Co., 1904.
Kohlrausch, Physical Measurements, third edition, D. Appleton & Co., 1899.
Mann, Advanced Optics, Scott, Foresman & Co., 1902.
Miller, Laboratory Physics, Ginn & Co., 1903.
Nichols, Laboratory Manual, Volume I, Macmillan & Co., 1894.
Preston, Theory of Heat, Macmillan & Co., 1894.
Sabine, Laboratory Course in Physical Measurements, Ginn & Co., old edition, 1902.
Stewart and Gee, Elementary Practical Physics, three volumes, Macmillan & Co.
Stratton and Millikan, Laboratory Experiments, University of Chicago Press, 1898.
Watson, Textbook of Physics, fourth edition, Longmans, Green & Co.
Whiting, Physical Measurements, four volumes, John Wilson & Son.

In a few cases it has not been possible to give a reference to any of the above manuals, and therefore the manner of carrying out the experiment has been described briefly.

In the cases of Experiments 2, 3, and 5, the results of actual experiments are given in order that the student may see how they should be recorded. For Experiments 21, 22, 210, and 211, the proper method of recording them is shown, although actual figures are not given. For Experiment 21, on the Law of the Simple Pendulum, a sample curve has been plotted.

Experience shows that each experiment will, as a rule, occupy one laboratory period of about three hours. If a student has two laboratory periods, of about this length of time a week, the maximum number of experiments that he will be able to perform during the academic year will be about sixty-four. Every student ought to be able to do at least fifty during the year. These could be apportioned in the following manner: Mechanics 12, Sound 4, Heat 10, Light 12, and Electricity and Magnetism 12.

It will be necessary for the Instructor to select from these experiments, those which in his judgment can be performed to the best advantage by the student. The nature of the experiments chosen will depend upon the character and quantity of the apparatus at the command of the Instructor, upon the previous experience of the student, and upon the course which the student is pursuing in College. Thus, for instance, some difference may advantageously be made in the work assigned respectively to Academic and Engineering students. And again there may be some difference in the assignments accordingly as the student is pursuing Physics as a major subject, or does not intend to take further work in it. Also some variation may perhaps be made for the different courses in Engineering; Mechanical, Civil, Electrical, and Chemical.

Some of the experiments can, in my opinion, be performed by the student with greater profit than others. Such experiments I have marked with a star.

Any experiment which a student has already performed creditably in a High School or Preparatory School should not, of course, be repeated.

Finally, I wish to express my indebtedness to Professor Louis Trenchard More and to Mr. William Bell Cartmel for valuable suggestions and advice given to me during the compilation of this list.

JAMES E. IVES.

July 28th, 1906.

INSTRUCTIONS TO THE STUDENT.

Every student is required to provide himself with the Physics Laboratory Notebook, sold at the University Book Store. This is large enough to contain the records of the work done in the Physical Laboratory during the entire academic year. It is made of cross-section paper so that curves can be plotted directly in it, thus avoiding the use of detached sheets.

The student's name, and the title of the course should be written on the label on the outside of the notebook, thus:

John A. Jones,
Physics 2.

and also on the inside of the book. On the back of the book a small label should be pasted with the student's name, or initials, upon it, so that when standing upon the book shelf it can be readily picked out from the others.

Observations and results should be recorded on the *right hand pages*, the *left hand pages* being used only for making *computations*, such as addition, subtraction, multiplication, and division, either directly or by the use of logarithms.

Always begin a new page for a new experiment. The *number* of the experiment, its *title*, and the *date* on which it is made should be recorded on the top of the page, thus:

October 4th, 1906.
Experiment 3.
The Micrometer Caliper.

All observations, results, and computations must be recorded directly in the note-book, and no scraps of paper must be used in the laboratory for any purpose whatever. By computations are meant all multiplications, divisions, additions, and subtractions, and all operations with logarithms. It is therefore intended that everything connected with the experiment should be recorded in the note-book. Also, no observations or computations having once been made in the note-book, should be erased. If it is necessary to discard an observation or computation, simply draw lines through it. If a whole page is to be discarded draw a line diagonally across the page and write upon the page "Discarded", and briefly state the reason. *No pages should on any account be torn out of the note-book*, as it is desired that the note-book should contain a *complete* record of the work done in the laboratory.

If another student performs an experiment with you, record his name.

Record the names of all pieces of apparatus used in an experiment.

Be careful to state the *units* used after every recorded measurement, and to state clearly in what units your final result is expressed.

Every experiment should be completely finished, computations as well as observations, before another is commenced.

Every student is required to provide himself with a copy of Jones' Logarithm Tables, published by George William Jones, at Ithaca, New York. This book contains not only tables of the logarithms of the numbers, and of the trigonometric functions, but also tables of the Naperian logarithms, of squares, cubes, square roots, cube roots, and of many other useful quantities. Logarithms should be used, wherever possible, in making calculations, as much time and labor will be saved by so doing, and the records in the note-book will be neater.

For excellent instructions for the plotting of curves, the student is referred to Appendix II, pp. 121-123 in Sabine's Laboratory Course in Physics. In connection with Experiment 21, on "The Law of the Simple Pendulum", a sample curve has been given, so that the student may see exactly how such a curve should be plotted. This curve shows, graphically, the relation of the *period* of a simple pendulum to its *length*. Such a curve may be used not only for the purposes of interpolation, but also to determine approximately the algebraic relation existing between the two quantities which are plotted. For this latter use, some knowledge of analytical geometry is necessary. If the note-book is made of cross-section paper the curves can be plotted directly in it. *If the curve is plotted on a separate piece of paper, it must be pasted securely in the note-book so that it cannot be lost.*

Excellent tables of physical constants will be found at the end of the various manuals referred to, especially in those of Kohlrausch, Miller, and Ames and Bliss. The Smithsonian Physical Tables published by the Smithsonian Institute will also be found useful.

Note-books will be marked not only for *proficiency* in Experimental Physics, but also for *cleanness*, *neatness*, *language*, and *accuracy*.

Note-books, when not in use, should be kept upon the book shelf provided for this purpose. When a student leaves the laboratory, the note-book should be placed in its proper compartment upon it.

The student is expected to assist the Instructor in every way, in his power, in keeping the laboratory, and everything in it, neat and in order. Lack of such care and thoughtfulness will lower the grade of the student.

MECHANICS.

*1. The Vernier.

Ames and Bliss, Experiment 4.

Read the reference and perform the experiment as described. Use at least three styles of Verniers.

*2. The Vernier Caliper.

Ames and Bliss, Experiment 5.

Determine the dimensions of three small metal cylinders, with the Vernier Caliper, and from their dimensions, calculate their volumes. Take three readings of the length, and six of the diameter for each cylinder. The measurements of the diameter should be taken in pairs, the two readings of a pair being taken at right angles to each other.

A sample set of results for this experiment is given below, in order that the student may see how they should be displayed.

EXAMPLE. *October 3rd, 1906.*

Experiment 2.

To find the volume of a cylinder with a Vernier Caliper.

	Length in Centimeters			Diameter in Centimeters			Mean Length in Centimeters	Mean Diameter in Centimeters	Volume $=\pi r^2 l$ in Cubic Centimeters
	Zero Reading	Reading on Cylinder	Difference	Zero Reading	Reading on Cylinder	Difference			
Cylinder No. 1.	.00 .01 −.01	3.02 3.02 3.00	3.02 3.01 3.01	.00 .01 .01 .01 −.01 .00	1.27 1.27 1.27 1.26 1.26 1.27	1.27 1.26 1.26 1.25 1.27 1.27	3.01	1.263	3.78
Cylinder No. 2.	.00 .00 .01	2.20 2.21 2.20	2.20 2.21 2.19	.00 −.01 .02 .00 .00 .00	1.00 1.00 1.01 1.00 1.01 .99	1.00 1.01 .99 1.00 1.01 .99	2.20	1.00	1.73
Cylinder No. 3.	.00 .01 −.01	1.64 1.65 1.63	1.64 1.64 1.64	.01 .00 .00 .00 .00 −.00	.88 .87 .88 .88 .86 .85	.87 .87 .88 .88 .86 .86	1.64	.87	.975

*3. The Micrometer Caliper.

Ames and Bliss, Experiment 6.

Read the reference, and determine the mean diameters of three wires, in the manner described. At least six readings should be made of the diameter of each wire. These readings should be taken in pairs, the two readings of a pair being at right angles to each other.

EXAMPLE. *October 5th, 1906.*

Experiment 3.

To determine the diameter of a wire with the Micrometer Caliper.

Zero Reading	Reading on the Wire	Difference in Centimeters	Mean Diameter in Centimeters
Wire No. 1.			
—.0006	.0800	.0806	.0805
—.0007	.0795	.0802	
—.0005	.0802	.0807	
—.0006	.0801	.0807	
—.0007	.0798	.0805	
—.0006	.0797	.0803	
Wire No. 2.			
—.0006	.1650	.1656	.1657
—.0007	.1651	.1658	
—.0005	.1649	.1654	
—.0007	.1647	.1654	
—.0006	.1655	.1661	
—.0007	.1650	.1657	
Wire No. 3.			
—.0007	.2765	.2772	.2771
—.0006	.2762	.2768	
—.0007	.2767	.2774	
—.0007	.2768	.2775	
—.0006	.2764	.2770	
—.0007	.2762	.2769	

4. The Protractor.

Stewart and Gee, Volume I, Lesson XIV.

Construct a graduated circle, in the manner described in the reference.

*5. The Spherometer.

Sabine, Experiment 3.

Determine the radius of curvature of a convex, or concave, lens or mirror.

Make at least five readings at different places on the lens, taking a new zero reading on the glass plate each time.

EXAMPLE. *October 10th, 1906.*

Experiment 5.

To find the radius of curviture of a lens with a Spherometer.

Reading to determine *a*.

Zero Reading	Reading on Lens	Difference in Centimeters	Mean *a* in Centimeters
.0025	.0565	.0540	.0546
.0025	.0570	.0545	
.0030	.0578	.0548	
.0026	.0576	.0550	
.0025	.0571	.0546	

Reading to determine *d*.

2.48 cm.
2.47 cm. mean $d = 2.48$ cm.
2.50 cm.

Therefore $R = \frac{a^2+d^2}{2a} = 56.3$ cm.

6. Measurement of Length with the Linear Dividing Engine.

Stewart and Gee, Volume I, Lesson VI.

7. Construction of a Scale with the Linear Dividing Engine.

Stewart and Gee, Volume I, Lesson VII.

8. The Circular Dividing Engine.

Miller, Experiment VI, §25.

9. The Planimeter.

Miller, Experiment XI, §§35, 36.

*10. The Level Tester.

Miller, Experiment X, §34.

Determine the sensitiveness of a Spirit Level in the manner described in the reference.

11. **The Micrometer Microscope.**

Miller, Experiment III, §21.

Determine the pitch of the screw of the micrometer both in inches and in centimeters, and find the ratio of the inch to the centimeter.

12. **The Comparator.**

Miller, Experiment IV, §22.

Compare an unknown length with a standard length.

*13. **The Telescope Cathetometer.**

Stewart and Gee, Volume I, Lesson IX.

Having made all the necessary adjustments of the Cathetometer, determine the errors in the readings of a metal scale by comparing it with the cathetometer scale, which may be assumed to be correct. Make readings every five centimeters, and plot a curve showing the corrections to be applied to the metal scale.

14. **The Microscope Cathetometer.**

Ames and Bliss, Experiment 10.

This instrument is intended for the measurement of small changes of length of three centimeters or less, to one thousandth part of a millimeter.

15. **The Chronograph.**

Miller, §68.

*17. **The Triangle of Forces.**

Miller, Experiment XIII, §38.

*18. **Equilibrium of Moments.**

Miller, Experiment XV, §40.

First, determine an unknown mass in the manner described in the reference.

Second, determine the weight of the meter-bar in the manner described.

Make three settings of the weights in each case, and take the mean.

*19. **Atwood's Machine.**

Ames and Bliss, Experiment 16.

20. **Determination of *g* with Atwood's Machine.**

Miller, §62.

*21. Law of the Simple Pendulum.

The object of this experiment is to determine the relation of the period of oscillation of a Simple Pendulum to its length.

To do this, let the pendulum swing through a small arc of 5 degrees or less, and find the complete period of oscillation when it is about 100, 70, 40, 30 and 20 centimeters long, respectively. The period can be found by noting the time of 100 complete vibrations with a watch, and then dividing this time by 100. The result is the period, or, the time which the pendulum takes to make one complete swing.

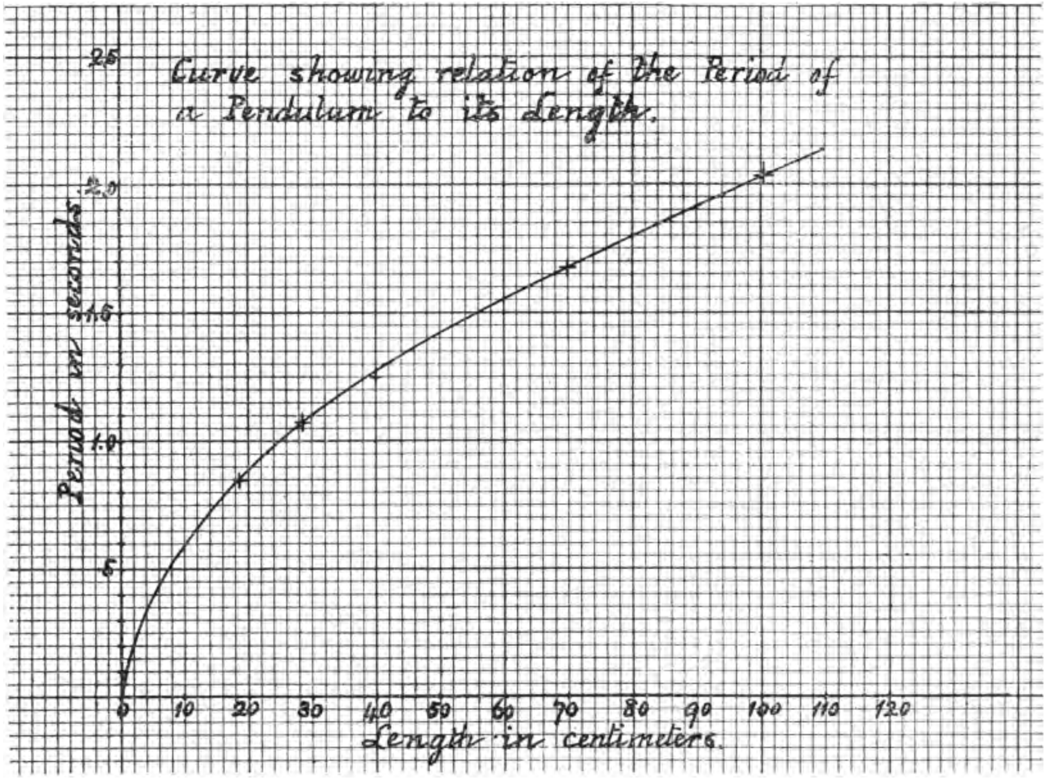
The length of the pendulum can be determined with sufficient exactness for this experiment by measuring the distance from the point of support to the top of the bob, and adding to this the radius of the bob.

With the results that you obtain, plot a curve representing the relation of the period of the pendulum to its length. Take the lengths as ordinates, and the periods as abscissas. A sample curve is given in the text to illustrate the method of plotting.

Divide the *square* of the period by the length in each case. Is the quotient a constant? If so, what is the relation of the period of a simple pendulum to its length? If this relation holds between the ordinates and abscissas of the curve which you have plotted, what is this curve called?

Record your results in a table of the following form:

Length in Centimeters	Period in Seconds	Period Squared	Period Squared Divided by the Length


Curve showing relation of the Period of
a Pendulum to its Length.
Period in seconds
25
2.0
1.5
1.0
5
0
10
20
30
40
50
60
70
80
90
100
110
120
Length in centimeters.

*22. Determination of g with the Simple Pendulum.

Miller, §§64, 65.

Make the length of the pendulum approximately 100 centimeters, and perform the experiment as described in Miller using the Method of Coincidences to determine its period. Close the sounder circuit of the Laboratory clock so that the sounder will tick seconds. You will not then need to use a watch. Count the ticks of the clock between two coincidences, and divide the total time elapsed by the number of coincidences less one, to get the time between two successive coincidences.

It will only be necessary to use one length of pendulum. The distance from the point of support to the bottom of the bob can be measured with a Beam Caliper, and the diameter of the bob with a Vernier Caliper.

Take at least three independent sets of observations using this length.

Make corrections for,

i. Length of the arc of swing.
ii. True length of the equivalent simple pendulum.
iii. The error of the Laboratory clock.

This experiment should be recorded as follows:

Date.

Experiment 22.

To determine g (the acceleration of gravity) by means of the simple pendulum, using the method of coincidences to determine the period of an oscillation.

Total Number of Coincidences.	Time between First and Last Coincidences in Seconds.	Mean Time between Two Successive Coincidences.	Period in Seconds.

Distance from the point of support to the bottom of the bob=
Radius of the bob=
Correction for true length of the equivalent simple pendulum=
Length of the arc=
Correction for length of the arc=
Correction for the error of the clock=
Corrected length=
Mean corrected period=

$$g=\frac{\pi^2 l}{t^2}=$$

23. Determination of g by Bessel's Method.

Stewart and Gee, Volume I, §166.

*24. The Compound Pendulum.

Hastings and Beach, §§62, 63.

Determine by experiment the period of the compound pendulum supplied, and then calculate it from the formula given in the reference, and see how closely the calculated and experimental values agree. In the calculation take into account the weight of the rod.

At what distance from the point of support is the centre of gravity of the system?

What is the length of the radius of gyration?

What is the length of the equivalent simple pendulum?

*25. Determination of g with Kater's Pendulum.

Miller, §§66, 67.

The period should be determined by the Method of Coincidences, and the distance between the knife edges measured with the Cathetometer.

27. Properties of the Path of a Projectile.

Miller, Experiment XXIII, §63.

28. Simple Harmonic Motion.

29. Composition of Simple Harmonic Motion and the Motion of Translation.

*30. Composition of Two Simple Harmonic Motions at Right Angles to Each Other. (Lissajous' Figures.)

Barker, §§58, 59.

Determine by experiment the figures formed by two harmonic oscillations at right angles to each other, having equal amplitudes, and having the following ratios of periods and differences of phase:

Periods	Difference of phase
1 : 1	0
1 : 1	¼
1 : 2	0
1 : 2	¼
1 : 2	½
2 : 3	0
2 : 3	⅛

The difference in period can be obtained by adjusting the positions of the weights.

In some way make a permanent record of these figures, either by using a pencil as the moving point, or by making the figures on smoked glass and then making blue-prints of them, Paste the figures so obtained in the note-book, marking on each one the period ratio, and the phase difference.

*32. Coefficient of Friction.

Ames and Bliss, Experiment 25.

*34. The Use of the Mercury Barometer.

Ames and Bliss, pages 157-159.

Make a careful reading of the Mercury Barometer in the Laboratory, using the attached Vernier, and reduce this reading, in the manner described in the reference to zero degrees centigrade, sea level, and latitude 45 degrees.

35. To Determine the Errors of an Aneroid Barometer.

Miller, Experiment XXXIV, §88.

*36. Reading a Balance by Vibrations.

Sabine, Experiment 6.

*37. Sensitiveness of a Balance.

Sabine, Experiment 7.

*38. Double Weighing with the Balance.

Sabine, Experiment 8.

*39. Weight in vacuo with a Balance.

Sabine, Experiment 9.

*41. Young's Modulus by Sketching a Wire.

Stewart and Gee, Volume I, §§117, 120.

42. Young's Modulus by the Bending of a Beam Supported at Both Ends.

Stewart and Gee, Volume I, §124.

Determine by this method Young's Modulus for Steel, using a rod of square cross-section.

Take readings of the bendings produced by the addition of loads increasing successively by 500 grams each time. Take observations for five different loads, and then take readings diminishing the load by 500 grams each time.

From the deflections so obtained, calculate the value of Young's Modulus.

The breadth and depth of the steel rod should be determined with a micrometer caliper, as it is necessary that these quantities should be measured as accurately as possible. Take three readings of each quantity at different points of the rod, and take the means.

Plot a curve showing the relations of the deflections to the loads. Plot loads as abscissas and deflections as ordinates. Does the curve so obtained confirm Hooke's law?

State in words what is meant by Young's Modulus.

43. Young's Modulus by the Bending of a Beam Supported at One End.

Stewart and Gee, Volume I, §125.

44. Poisson's Ratio by Stretching.

Stewart and Gee, Volume I, §131.

46. Tenacity.

Stewart and Gee, Volume I, §133, 134.

49. The Ballistic Pendulum.

Miller, Experiment XIV, §39.

52. The Laws of Torsion.

Miller, §81.

*53. Moment of Inertia by the Torsion Pendulum.

Sabine, Experiment 18.

*56. Coefficient of Rigidity with the Torsion Lathe.

Miller, §80.

57. **Coefficient of Rigidity with the Torsion Pendulum.**
Ames and Bliss, Experiment 28.

61. **Density of a Solid by Measuring its Weight and Volume.**
Kohlrausch, §13, I, B, 1, page 46.

*62. **Specific Gravity of Solids with the Hydrostatic Balance.**
Ames and Bliss, Experiment 31.

*63. **Specific Gravity of Solids with Jolly's Balance.**
Miller, Experiment XLIV, §102.

The Jolly Balance depends for its action upon Hooke's Law, which says, that, for elastic bodies, the elongation is proportional to the stretching force. Since a helical spring is an elastic body, it obeys this law.

The experiment may profitably be divided into two parts, namely, (1) to verify Hooke's Law, and (2) to determine the Specific Gravity of one or more solids.

Part I. To Verify Hooke's Law.

Level the instrument carefully, so that the index does not rub against the sides of the glass tube which surrounds it. Then bring the index to zero, and measure with a meter stick the distance between the fixed and movable marks. Estimate to tenths of a millimeter. Add successive weights of the values 1, 2, 3, 4 and 5 grams respectively, and record the elongation of the spring in each case, Divide each of these elongations by the weight which produced it. If the experiment has been performed carefully, the quotient will be the same in each case. This shows that the elongation varies directly as the stretching force, and that Hooke's law holds for a helical spring.

Plot a curve showing the relation between the stretching force, and the resultant elongation. Plot the weights as abscissas and the elongations as ordinates. Since the elongation varies directly as the stretching force, the resultant curve should be a straight line. The elongation is therefore said to be a *linear function* of the stretching force.

Part II. To Determine the Specfic Gravity of Solids.

Use the instrument as explained in the reference to determine the Specific Gravity of two or more solids.

*64. Specific Gravity of Solids with Nicholson's Hydrometer.

Ames and Bliss, Experiment 32.

Determine with this instrument the density of lead, nickel, coin silver, copper, brass, iron and aluminum. Make the determination of these specific gravities just as accurately as you can with this instrument. Be on the alert to detect all possible sources of error, and perform the experiment with great care.

65. Specific Gravity of Solids with the Pyknometer.

Miller, §97, *Density of a Solid in Fragments*.

*67. Density of Liquids with the Pyknometer.

Stewart and Gee, Volume I, Lesson XXXII.

Make, by this method, an *exact* determination of the density of alcohol. Weigh to tenths of a milligram by the method of vibrations; use the method of double weighing; and make corrections for the buoyancy of the air.

68. Specific Gravity of Liquids with Mohr's Balance.

Stewart and Gee, Lesson XXXVI, Method III.

This instrument gives the Specific Gravity of Liquids directly in terms of water at 15° C.

Determine the densities of five different liquids, as for example, of Alcohol, Kerosene, Turpentine, Olive Oil, and Glycerine.

69. Specific Gravity of Liquids with Baumé's Hydrometer.

Stewart and Gee, Volume I, §97.

Make a 2, 4, 6, 8 and 10 per cent. solution of common table salt (sodium chloride), and determine the density of each solution by means of a Baumé Hydrometer. Record your results in degrees Baumé, and also in terms of absolute density. The relation of absolute density to degrees Baumé, may be found in Table Q in the reference. A 2 per cent. solution means 2 parts by weight of salt to 98 parts by weight of water. Observe and record the temperature of the solution in each case.

With the results that you obtain from this experiment, plot a curve showing the relation of the absolute densities of the solutions to their concentrations. Take concentrations for abscissas, and absolute densities for ordinates.

*70. Specific Gravity of Liquids with Balancing Columns.

Miller, §100.

Determine the Specific Gravity of Mercury by this method, using a meter stick to measure the heights of the liquid columns. Measure to the highest point of the Mercury meniscus, and to the lowest point of the water meniscus. Make the lengths of the balancing columns as great as possible, for the longer they are, the more accurate will be the results. Make all the measurements very carefully, otherwise the value obtained for the density will not be satisfactory.

72. Density of Air by Exhaustion.

Miller, Experiment XLI, §98.

73. Density of a Gas by Weighing.

Miller, Experiment XLII, §99.

76. Velocity of Efflux of a Liquid: Torricelli's Theorem.

Ganot's Physics, Fifteenth Edition, §144.

77. Flow of Liquids in Tubes: the Pressure Head.

Barker, §182.

*81. Boyles Law.

Miller, Experiment XXXIII, §87.

82. To Determine the Gas Constant.

Hastings and Beach, §138.

85. The Angle of Contact.

Hastings and Beach, §108.

Determine the angle of contact of mercury with glass by varying the *inclination* of a glass plate immersed in mercury until the line of contact between the mercury and the glass, lies in the plane of the surface of the mercury, on one side of the glass plate. In order to get good results the glass plate and the mercury must *both* be very clean. Clean the glass plate first with dilute nitric acid, and then with a solution of caustic soda. This is best done with a small swab made of a piece of clean linen rag tied around the end of a small glass rod. Take six readings altogether; three readings turning the plate downward from the vertical position, and three readings turning it upward from the horizontal.

*86. Surface Tension with Capillary Tubes.

Sabine, Experiment 15.

Perform the experiment as described in the reference, using two capillary tubes of different internal diameters. Determine the Surface Tension of both water and alcohol.

Remember that the complete formula for surface tension as deduced from the rise of a liquid in a capillary tube is given by

$$T=\frac{h\rho rg}{2\cos\alpha}$$

where

T is the surface tension.
h, the height of rise of the liquid in the tube.
ρ, the density of the liquid.
r, the radius of the tube.
g, the acceleration of gravity.
α, the angle of contact for the liquid used.

For water $\rho=1$.

For alcohol $\rho=.79$.

For water in contact with glass in air $\alpha=0$.

For alcohol in contact with glass in air $\alpha=0$.

For mercury in contact with glass in air, α is equal to about 136°. Therefore the surface of mercury is depressed in a capillary tube.

*87. Surface Tension by Direct Measurement.

Miller, Experiment XXXVII, §92.

Find by this method the surface tension of two liquids; for example of water and of alcohol.

*91. Coefficient of Viscosity by the Rate of Flow Through Small Tubes.

Kohlrausch, Experiment 37 C.

Before beginning this experiment the student should read §183 in Barker's Physics.

Determine by the method described in Kohlrausch the Coefficient of Viscosity of water. Distilled water should be used for this experiment, and a correction made for the velocity of flow in the capillary tube. If the outer end of the tube is immersed in the water in the receiving vessel, the total height h is the distance from the surface of the water in the reservoir to the surface of the water in the receiving vessel. The radius of the capillary tube can be determined by drawing into it a thread of mercury from ten to twenty centimeters long, placing this thread in three positions along the tube and measuring its length in each position. The mean of the three lengths is then taken and the mercury is taken out of the tube and weighed. From the length and weight of the thread and the density of mercury, the mean radius of the tube can easily be calculated.

92. **Coefficient of Viscosity with the Torsion Pendulum.**
Miller, Experiment XXXVIII, §93.

94. **Compressibility of a Liquid with the Piezometer.**
Miller, Experiment XXXII, §86.

95. **The Pressure of Moving Air.**

99. **Change of Volume with Solution.**

SOUND.

101. **Transmitsion of a Wave Along a Heavy Cord.**

102. **Transmission of a Wave Along a Helical Spring.**
Ames and Bliss, Experiment 38, Part 1.

103. **Transmission of a Wave on the Surface of Water.**
Ames and Bliss, Experiment 38, Part 2.

*106. **Laws of Vibrating Strings with the Sonometer.**
Miller, §119.

108. **Melde's Experiment.**
Stewart and Gee, Volume III, Experiment LXIII.

111. **Transverse Vibrations of a Rod Fixed at One End.**
Stewart and Gee, Volume III, Experiment XL.

112. **Transverse Vibrations of a Rod Free at Both Ends.**

113. **Longitudinal Vibrations of a Rod.**

115. **Properties of a Tuning Fork.**
Stewart and Gee, Volume III, Experiments XLVIII–LIV.

*121. **Frequency of a Tuning Fork with the Monochord.**
Sabine, Experiment 19.

*122. **Frequency of a Tuning Fork with the Chronograph.**
Miller, Experiment LII, §108.

123. **Frequency of a Tuning Fork with the Stroboscope.**
Kohlrausch, 37 A (2).

124. **Frequency of a Tuning Fork by Lissajou's Figures.**
Miller, §109.

125. **Frequency of a Tuning Fork by the Method of Beats.**
Glazebrook and Shaw, Experiment 27.

126. **Frequency of a Tuning Fork by Optical Comparison.**
Miller, §§112, 113.

141. **Properties of a Vibrating Column of Air.**
Ames and Bliss, Experiment 43.

142. **Frequency of an Organ Pipe with the Siren.**
Stewart and Gee, Volume III, Experiment XXXVIII.

143. **Determination of the Overtones in an Organ Pipe.**
Sabine, Experiment 23.

151. **The Properties of Vibrating Plates.**
Stewart and Gee, Volume III, Experiments XLII–XLVII.

*161. **Velocity of Sound in Air, with Tube and Diaphragm.**
Sabine, Experiment 21.

162. **Velocity of Sound in Air, with Tube and Water.**
Ames and Bliss, Experiment 40.

163. **Velocity of Sound in Air by Interference.**
Miller, Experiment LVII, §118.

*164. **Velocity of Sound in Metals with Kundt's Dust Figures.**
Sabine, Experiment 22.

165. **Velocity of Sound in a Gas.**
Miller, Experiment LVII, §118.

166. **Relative Velocity of Sound in Metals.**
Ames and Bliss, Experiment 42.

171. **Young's Modulus with Kundt's Dust Figures.**
Miller, §117.

172. **Young's Modulus for the Steel of a Tuning Fork.**
Stewart and Gee, Volume III, Experiment LX.

175. **Energy of Vibration of a Tuning Fork.**
Stewart and Gee, Volume III, Experiment LXI.

177. **Determination of g with a Tuning Fork.**
Stewart and Gee, Volume III, Experiment LXIV.

181. **The Structure of the Musical Scale.**
Sabine, Experiment 20.

183. **Quality by the Manometric Flame.**
Sabine, Revised Edition, Experiment 9.

185. **Composition of a Sound with Resonators.**
Miller, §124.

191. **Properties of Singing Flames.**
Stewart and Gee, Volume III, Experiments CXIX–CXXI.

192. **Properties of Sensitive Flames.**
Stewart and Gee, Volume III, Experiments CXXV–CXXVII.

193. **Determination of Wave-length with a Sensitive Flame.**
Glazebrook and Shaw, Experiment 31.

HEAT.

*201. **Determination of the Fixed Points of a Mercury Thermometer.**
Ames and Bliss, Experiment 44.

202. **Calibration of the Bore of a Mercury Thermometer.**
Miller, §129.

Plot a curve showing the corrections to be applied to the reading of the thermometer on account of the variation in the bore of the tube. Take thermometer readings for abscissas and corrections for ordinates.

*203. The Air Thermometer.

Miller, §134.

Determine with this instrument the temperature of the Laboratory, and also the Coefficient of Expansion of air.

Be very careful not to break off the glass bulb, and, also, not to allow the mercury to run over into it.

204. The Weight Thermometer.

Preston, §79.

205. The Pyrometer.

210. Vapor Density by Dumas' Method.

Kohlrausch, §16, A.

Determine, by this method, the density of Ether Vapor.

Since Ether boils at 34.9° C, a water bath may be used. The moment at which all the ether is vaporized may be determined by lighting the issuing jet. When the liquid is completely vaporized the flame becomes very small. The bulb should then be immediately sealed, and a reading taken of the temperature of the bath. The water in the bath should be stirred continuously so as to make the temperature uniform throughout.

The results should be recorded as follows:

Date.

Experiment 210.

To determine the Relative Vapor Density of Ether by Dumas' Method.

m =Weight of bulb full of air=

m'=Weight of bulb full of ether vapor=

M=Weight of bulb full of water=

t =temperature of vapor at moment of sealing=

b =barometric pressure at moment of sealing=

t' =temperature of air in balance case when vapor was weighed=

b' =barometric pressure when vapor was weighed=

λ' =density of air at t' degrees and b' centimeters= (taken from the tables).

Relative Density of Ether Vapor=

$$\left(\frac{m'-m}{M-m}\cdot\frac{1}{\lambda'}+1\right)\left(\frac{b'}{b}\cdot\frac{1+.00367t}{1+.00367t'}\right)=$$

*211. **Vapor Density by Mayer's Method.**

Kohlrausch, §16, C.

Determine the relative vapor density of some volatile liquid, such as ether or chloroform, by this method.

If ether is used, since it boils at 34.9° C, water may be used in the outer tube. The water should be made to boil violently so that the temperature of the bath may be uniform throughout its length. Before beginning the experiment, the old asbestos should be taken out of the inner tube, and all ether vapor or water which may have been left in it from some previous experiment should be sucked out with the suction pump. Since the ether in the small flask, which is dropped into the inner tube, evaporates very rapidly, the flask should be weighed full at the convenience of the experimenter, and then filled up again just before dropping it into the tube. The flask should be handled with a pair of forceps and *not* with the fingers as the heat of the fingers will cause the ether to evaporate.

After the experiment is finished, be sure to remove the rubber stopper from the end of the inner tube, otherwise water will be sucked back into it, as the vapor inside it cools.

The results should be recorded as follows:

Date.

Experiment 211.

To determine the relative density of Ether Vapor by Mayer's Method.

Weight of empty flask=
Weight of flask filled with ether=
m =weight of the ether=
t =temperature of the room=
H=barometric pressure=
v =volume of air displaced=

$$\text{Relative density of Ether Vapor} = \frac{m}{v} \cdot \frac{760}{H} \cdot \frac{1 + .004t}{.001293}$$

*215. **Vapor Tension by Dalton's Method.**

Ames and Bliss, Experiment 55, Method 2.

Determine by this method the vapor tension of some volatile liquid, such as ether or chloroform, for five different temperatures, between 50° C and the temperature of the room. To do this, begin with the water in the water jacket at a temperature of about 50°C, and allow it to cool to the temperature of the room. To get good results, the water in the water jacket should be kept well stirred, and both *the tube and the mercury should be perfectly clean and dry before beginning the experiment.*

Plot a curve with the results obtained showing the relation between vapor tension and the temperature. Plot temperature as abscissas, and tensions as ordinates.

216. Vapor Tension of Solutions.

Kohlrausch, §27 A.

220. Coefficient of Linear Expansion with the Lever and Scale.

Ames and Bliss, Experiment 45.

*221. Coefficient of Linear Expansion with the Micrometer Screw.

Whiting, Volume I, ¶57.

222. Coefficient of Linear Expansion with the Comparator.

Miller, §125.

230. Coefficient of Cubical Expansion of Solids.

Ames and Bliss, Experiment 47.

*231. Coefficient of Apparent Cubical Expansion of Mercury with the Weight Thermometer.

Hastings and Beach, §127.

Determine the apparent expansion of mercury in glass with the Weight Thermometer in the manner described in the reference.

For this purpose, construct a Weight Thermometer having a bulb about two inches long and half an inch wide. Fill it with mercury by alternately heatimg it and allowing the mercury to be sucked up into it as it cools. After it is filled, immerse the bulb in water at the temperature of the room. Determine the temperature of the water and then gradually heat the water until it boils. Collect the mercury driven off as the temperature of the water rises and weigh it. The water should be stirred continuously.

The results may be recorded as follows:

Date.

Experiment 231.

To determine the Coefficient of Apparent Cubical Expansion of Mercury with a Weight Thermometer.

m = weight of mercury drawn off =
W = weight of thermometer with mercury remaining in it =
w = weight of thermometer empty =
t_1 = temperature of the cold water =
t_2 = temperature of the boiling water =

Coefficient of apparent cubical expansion of mercury in glass

$$= \frac{m}{(W-w)(t_2-t_1)}$$

***232. Coefficient of Cubical Expansion of Liquids with the Pyknometer.**

Sabine, Experiment 26.

233. Coefficient of Cubical Expansion of Liquids by the Method of Equilibrating Columns.

Preston, §102·

234. Coefficient of Cubical Expansion of Liquids with the Dilatometer.

Miller, §127.

240. Coefficient of Cubical Expansion of Gases.

***243. To Determine the Temperature of the Greatest Density of Water.**

***245. Specific Heat of Solids by the Method of Mixtures.**

Ames and Bliss, Experiment 49.

247. Specific Heat by the Method of Cooling.

Kohlrausch, §30.

***248. Specific Heat of a Solid by Black's Method.**

Miller, Experiment LXXVII, §142.

*249. Specific Heat with the Ice Calorimeter of Lavoisier and Laplaee.

Ganot, §459.

*250. Specific Heat with the Ice Calorimeter of Bunsen.

Miller, §143.

251. Specific Heat with the Steam Calorimeter of Joly.

Preston, §§136, 137.

*260. Ratio of the Two Specific Heats of a Gas by the Method Clement and Desormes.

Preston, §147.

*265. Latent Heat of Fusion of Ice.

Sabine, Experiment 28.

Let the water in the Calorimeter be at about 30° C when you begin the experiment, and add ice until it has been cooled to about 10° C. You will thus start with the temperature of the water about 10° above, and cool it to about 10° below the temperature of the room. In this way, you will largely get rid of the error due to radiation, and to convection currents in the air. The pieces of ice used should be about the size of small walnuts, and the student should be careful that the ice is dry before putting it into the calorimeter. The quantity of ice put in can be determined by weighing the calorimeter and its contents at the beginning of the experiment before any ice is put in, and again at the close of the experiment. The difference between these two weights will be the weight of the ice melted. If

m_1=mass of water in calorimeter at beginning.
m_2=mass of ice added.
a =thermal capacity of calorimeter.
L =Latent Heat of ice.
t_1 =temperature of water in calorimeter at beginning.
t_2 =final temperature of water.

Then

$$L m_2 + m_2 t_2 = m_1 (t_1 - t_2) + a (t_1 - t_2)$$
$$= (m_1 + a)(t_1 - t_2)$$

and

$$L = \frac{(m_1 + a)(t_1 - t_1)}{m_2} - t_2$$

*267. Latent Heat of Vaporization of Water.

Whiting, Experiment XXXVII, ¶¶103, 104.

270. The Melting Point of a Simple Body.

Sabine, Experiment 25.

Determine the melting point of paraffine. Instead of using the capillary tube described in the reference, put the paraffine in a small test tube and place the thermometer directly in it.

271. The Melting Point of a Solution.

Kohlrausch, §26 A.

275. The Boiling Point of a Simple Body.

Ames and Bliss, Experiment 53.

*276. The Boiling Point of a Solution.

Make up a 5, 10, 15, 20 and 25 per cent. solution of common table salt (Sodium Chloride), and determine the boiling point in each case.

With your results, plot a curve showing the variation of the the boiling point with the concentration, using concentrations for abscissas, and boiling points for ordinates.

*278. The Critical Temperature.

Preston, §209.

A small glass tube hermetically sealed is about half full of ether. This tube is completely immersed in a bath of melted paraffin which is gradually heated to nearly 200° C. The critical temperature can be determined by noting the temperature at which the menicus disappears. An observation should be made as the menicus disappears with rising temperature, and also as it reappears again as the ether cools. The mean of the two readings will give the best value. At least three independent sets of reading should be made.

280. Thermal Conductivity of Solids.

281. Thermal Conductivity of Liquids.

*282. Mechanical Equivalent of Heat with Puluj's Apparatus.

Miller, §150.

283. **Radiation of Heat.**
Ames and Bliss, Experiment 56.

284. **Heat of Solution.**
Whiting, ¶99.

Determine the Latent Heat of solution of Common Table Salt (Sodium Chloride) by the method described in the reference, using 10, 20, 30, 40 and 50 grams of salt respectively to 100 grams of water.

285. **Heat of Combination.**
Whiting, ¶¶105, 106.

286. **Heat of Combustion.**
Whiting, ¶107.

*290. **Regnault's Hygrometer.**
Miller, §151.

Determine the Relative Humidity of the air in the Laboratory with this instrument.

After having made this determination also determine it with the United States Weather Bureau Psychrometer (see Miller, p. 200), and note how closely the two values agree with each other.

The relative humidity can be determined from the readings of the hygrometers by means of Tables 20 and 21 in Miller.

*291. **Daniell's Hygrometer.**
Ganot, §402.

Determine the Relative Humidity of the air in the Laboratory with this instrument.

After making this determination, also determine it with the United States Weather Bureau Psychrometer (see Miller, p. 200), and note how the results obtained with the two instruments compare with each other.

The relative humidity can be obtained from the readings of these instruments by means of Tables 20 and 21 in Miller.

*292. United States Weather Bureau Pyschrometer.

Miller, pages 200-202.

Determine the Relative Humidity of the air in the Laboratory with this instrument.

Compare the result with a reading made either with the Regnault or the Daniell Hygrometer.

295. The Variation of Solubility with the Temperature.

Determine the solubility of some salt for different temperatures, and plot the results.

*296. The Phenomenon of Surfusion.

Preston, §156.

Determine how low the temperature of water can be made to fall before it freezes.

Make a freezing mixture of about two-thirds broken ice and one-third table salt. In this, place a test tube containing distilled water which has been previously boiled for some time and then filtered. In the test tube, suspend a thermometer reading to about 20° C, so that the bulb of the thermometer is covered by the water. The temperature of the water in the test tube will fall rapidly, and will probably go below zero degrees centigrade before the water freezes. *You can tell when the water freezes by a sudden rise in the reading of the thermometer.* Record the thermometer readings every 30 seconds as the temperature falls. Make at least five independent sets of observations. The more carefully the experiment is performed, the greater will be the depression of the freezing point.

LIGHT

301. Angle of a Prism with the Gaussian Eye-piece Spectrometer.

Ames and Bliss, Experiment 87, Method 1.

*302. Angle of a Prism with the Fixed Table Spectrometer.

Ames and Bliss, Experiment 87, Method 2.

*303. Angle of a Prism with the Movable Table Spectrometer.

Ames and Bliss, Experiment 87, Method 3.

305. Angles of a Crystal with the Wollaston Goniometer.

Miller, Experiment CV, §170.

306. Angles with the Sextant.

Miller, Experiment XII, §37.

Measure with this instrument the angle between two of the towers seen to the east of the Laboratory. Any two may be chosen, but you should state in your notes which two you used. Be careful to determine the index correction, and to apply it to your readings.

308. The Measurement of Small Distances with the Optical Micrometer.

Miller, Experiment IX, §§31-33.

*311. Index of Refraction with the Spectrometer by the Method of Minimum Deviation.

Ames and Bliss, Experiments 88 and 89.

312. Index of Refraction by the Method of Total Reflection.

Kohlrausch, §40, Part IV.

313. Index of Refraction by Displacement.

Miller, Experiment CX, §181.

314. Index of Refraction with a Microscope.

Miller, Experiment CIX, §180.

*315. Index of Refraction with the Abbe Refractometer.

Kohlrausch, §40, Part III.

1. Measure with this instrument the Index of Refraction, for *sodium light*, of water, alcohol, and of some of the aromatic oils.

2. Repeat the measurements with *white light*, using the compensator and compare the results obtained in the two cases.

The temperatures at which the measurements are made should be recorded.

After the experiment is finished, carefully clean the glass prisms of the instrument with a soft clean linen cloth.

*316. Index of Refraction of a Liquid with a Lens.

Ganot's Physics, Fifteenth Edition, §574.

Some of the liquid is placed between a double convex lens and a piece of plate glass. The liquid then forms a plano-concave lens, the curvature of which is equal to, but of opposite sign to that of the face of the convex lens which it touches.

The theory of optics shows that the principal focus of the combination of the two lenses is given by the formula

$$\frac{1}{F}=\frac{1}{f}-\frac{1}{f'}$$

where F is the principal focus of the combination; f, the principal focus of the double convex lens; and f', the principal focus of the concave lens.

From this formula we obtain directly

$$f'=\frac{fF}{F-f}$$

f and F can be found experimentally by the the Method of Conjugate Foci described in Experiment 321.

Having determined f and F by experiment, and from their values calculated f' the principal focus of the plano-concave liquid lens, we can, if we know its radius of curvature, compute the index of refraction of the liquid which forms it. For a plano-concave lens having a principal focus f', a radius of curvature r, and an index of refraction n, we have the formula·

$$\frac{1}{f'}=(n-1)\frac{1}{r}$$

From which we obtain

$$n=\frac{r}{f'}+1$$

r is equal to the radius of curvature of the surface of the convex lens touching the liquid, but with the opposite sign, since the surface of the liquid being concave r is negative. It can be determined either with the Spherometer (Experiment 5) or by the Method of Reflection (Experiment 342).

Determine, by this method, the Index of Refraction of water.

317. Index of Refraction with the Michelson Interferometer.

Mann, Chapter V, Experiment III.

Before beginning the experiment read pages 48-55 in the reference.

*321. Principal Focus of a Convex Lens by the Method of Conjugate Foci.

The object of this experiment is to determine the principal focal distance of a convex lens.

If a convex lens is placed at a distance p from a source of light, an image of this source will be formed at a distance q on the other side of the lens. The theory of optics shows that

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

where f is constant for a given lens, and is called its principal focal distance, because it is the distance from the lens at which parallel rays entering it are focused. Corresponding values of p and q are called conjugate focal distances, and the points themselves at which the object and image exist are called conjugate foci.

To perform the experiment, place the lens at any convenient distance p from the bright source of light which serves as an object, and move the screen on the other side of the lens to and fro until a position is found in which a sharp image of the object is formed upon it. This distance of the screen from the lens is q, and p and q are conjugate focal distances. Having determined p and q for this case, change the distance p and find the corresponding value of q. Find, in this manner, five pairs of values of p and q, and compute f for each case. The mean of these five values of f will give the pincipal focal distance of the lens.

322. Principal Focus of a Concave Lens by the Shadow Method.

Sabine, Experiment 41.

*323. Principal Focus of a Concave Lens by combining it with a Convex Lens, so that the lenses touch each other.

Stratton and Millikan, Experiment 35*b*.

Fasten the two lenses together with a rubber band, and determine the principal focus of the combination by the method of Conjugate Foci (Experiment 321). Having done this, determine by the same method the principal focus of the convex lens by itself. In each case make five pairs of readings.

Knowing the principal focal distance F of the combination, and also F of the convex lens, you can calculate the principal focal distance of the concave lens F_2, from the formula

$$\frac{1}{F_2} = \frac{1}{F} - \frac{1}{F_1}$$

or $$F_2 = \frac{F_1 F}{F_1 - F}$$

*324. Principal Focus of a Concave Lens by combining it with a Convex Lens, the lenses not touching each other.

Miller, §166.

Make five pairs of readings. Calculate the principal focal distance for each pair, and take the mean of these values.

*325. Magnifying Power of a Convex Lens.

Sabine, Experiment 40.

Take five pairs of readings and plot a curve showing the relation of the magnifying power to the distance of the lens from the object.

*331. Magnifying Power of a Telescope.

Glazebrook and Shaw, §56.

Make five observations of the magnifying power with the scale at different distances from the telescope. Begin with the scale about three meters away from the telescope, and then move it in about fifty centimeters at a time.

Plot a curve with the results showing the relation of the magnifying power to the distance.

333. Construction of a Microscope.

Ames and Bliss, Experiment 86.

*334. Use of the Microscope.

Watson, §357.

A box of microscopical preparations will be given to the student. Each slide has mounted upon it some object suitable for observation under the microscope. Carefully observe each object using different objectives and eye-pieces to change the magnification. Make careful drawings in your note-book of the magnified images of at least two of these objects.

*335. Magnifying Power of a Microscope.

Kohlrausch, §45, III, (1).

Make a determination of the magnifying power of a microscope, using at least two objectives of differing powers and two eye-pieces.

336. Angular Aperture of a Microscope.

Kohlrausch, §45, III, (3).

341. Radius of Curvature of a Mirror with the Spherometer.

Kohlrausch, §43, I.

*342. Radius of Curvature of a Convex Mirror by Reflection.

Sabine, Experiment 35.

*343. Radius of Curvature of a Concave Mirror by the Method of Conjugate Foci.

Sabine, Experiment 34.

344. Radius of Curvature of a Mirror of Slight Curvature by the Method of the Virtual Focus.

Kohlrausch, §43, III.

*355. Spectrum Analysis with a Flame Spectrum.

Sabine, Experiment 44.

1. Determine the characteristic lines of Sodium, Barium, Strontium, Lithium, Calcium and Potassium. Make diagrams in your note-book showing the positions of these lines in the spectrum for each of these elements.

2. Having mapped the lines for each of these elements, determine the composition of three unknown mixtures of them made up by the Instructor.

Before using the spectroscope, two important adjustments should be made.

i. Adjust the observing telescope for parallel rays by focusing it on a distant object, such as a church spire.

ii. Keeping the observing telescope adjusted for parallel rays, move the slit of the collimating telescope in and out, until its image, as seen through the observing telescope, is clear and distinct.

356. Spectrum Analysis with a Spark Spectrum.

Sabine, Experiment 45.

357. Spectrum Analysis with an Absorption Spectrum.

Sabine, Experiment 46.

358. The Solar Spectrum.

Sabine, Experiment 47.

359. Dispersion Curve of a Prism with the Bunsen Spectrometer.

Miller, §201.

Determine the scale readings of the instrument for the spectral lines of Potassium, Lithium, Sodium and Strontium. Look for the wave-lengths of these lines in Kohlrausch's table, and then plot a curve in which ordinates represent wave-lengths and abscissas scale readings. Then from this dispersion curve determine the wave-lengths of several of the Barium and Calcium lines.

*364. Photometry with the Bunsen Photometer.

Sabine, Experiment 31.

Determine the candle power of an incandescent electric lamp in its three principal positions, namely with the filament face on, edge on and end on. Take three pairs of readings for each position. Calculate the candle power for each pair of readings, and take the mean of the nine values thus obtained for the mean candle power.

*365. Photometry with the Rumford Photometer.

Whiting, Experiment XL, II.

371. Wave Length by Interference using Newton's Rings.

Kohlrausch, Experiment 42, (2).

*372. Wave Length by Interference using Michelson's Interferometer.

Mann, Chapter V, Experiment I.

Read the theory of this instrument on pages 48-55 of the reference, and perform Experiment I,

373. Ratio of the Wave Lengths of Sodium Light with the Michelson Interferometer.

Mann, Chapter V, Experiment II.

Read the theory of this instrument on pages 48-55 of the reference, and perform Experiment II.

*375. Wave Length with the Transmission Grating; the Incident Light being normal to the Grating.

Kohlrausch, Experiment 42 (1).

Before beginning the experiment read the theory of it in Watson, §377.

The grating supplied for this experiment was made by photography, and has 6480 lines to the inch.

376. Wave Length with a Transmission Grating by the Method of Minimum Deviation.

Miller, §189, last paragraph.

377. Wave Length with a Reflection Grating.

Miller, §189.

*381. The Phenomenon of the Polarization of Light.

Barker, §§448-457.

Examine reflected and refracted light with a Nicol's prism, and record the results of your observation. Also record the behavior of light passing through a pair of Tourmaline Tongs as one of the Tourmaline crystals is rotated.

What is meant by the polarization of light? How can it be achieved? And how observed? In how many different ways can light be polarized?

382. Babinet's Compensator.

Kohlrausch, Experiment 47 B.

*383. Norremberg's Polariscope.

Ganot, §671.

Observe, and record with drawings, the appearance of sections of a number of crystals, (1) when the upper mirror is parallel to the lower one, and (2) when rotated through 90°. Do this both for parallel light and for convergent light.

*384. Specific Rotation with Laurent's Polarimeter.

Miller, §§203-205.

Determine the Specific Rotation of Cane Sugar, using solutions of 5, 10, 15, 20 and 25 grams of sugar to 100 grams of solution, respectively.

*385. Specific Rotation with Wild's Polarimeter.

Miller, §203 and §204, Interference Bands (Wild).

Determine the Specific Rotation of Cane Sugar, using solutions of 5, 10, 15, 20 and 25 grams of sugar to 100 grams of solution, respectively.

*391. Color Analysis with Maxwell's Disks.

Ames and Bliss, Experiment 90.

1. Try any combination of normal colors mixing by them by rotation of the disks. Match the resultant color with one of the colors in Prang's small book of colors. Try several combinations.

2. To each of the normal colors add portions of white light by using part of a white disk, observe the effect as more and more of the white disk is used.

3. Do the same thing with a black disk.

4. Find several pairs of complementary colors by combining certain of the normal colors in such proportions that they form a neutral gray. *This differs from white only in illumination.* The different colors should be so combined that the circle is divided in two equal parts, one of which is occupied by the color whose complement is to be found. The two halves of the circle should give equal illuminations. This can be adjusted by the use of white or black disks.

Suppose, for instance, that the following colors, combined in the given proportions, make a gray

Normal red . .	.4
Normal blue . .	.1
Normal green . .	.45
White	.05

We then find the resultant of the green and white, by combining them alone, and match it. The resultant of red and blue is found in the same way. These two resultant colors are complementary. Record your results by constructing miniature disks representing the colors actually used, and pasting them in the note-book. The resultant colors which are complementary to each other can be given either by pieces of the colored papers which match them, or by their names taken from Prang's book of colors.

392. Color Analysis with the Color Box.

Watson, §400.

393. Color Analysis with the Spectroscope.

395. Selective Absorption of Light with the Spectroscope.

Watson, §386.

397. Anomalous Dispersion.

Watson, §389.

Observe the spectrum of white light, first with a solid glass prism, and then with a hollow glass prism filled with a solution of Fuchsine in alcohol. Record the results, making a drawing of the spectrum in each case.

ELECTRICITY AND MAGNETISM.

*401. Magnetic Field of Force with Iron Filings.

Sabine, Experiment 48.

Examine and draw in the note-book: (1) Field of Force of one magnet by itself; (2) of two magnets, placed end to end, with their *unlike* poles opposite to each other; (3) of two magnets, placed end to end, with their *like* poles opposite to each other; (4) of two magnets, side by side, unlike poles opposite; (5) of two magnets, side by side, like poles opposite; and (6) Field of Force of the end of one of the magnets in a plane at right angles to its axis.

***402. Magnetic Field of Force with a Magnetic Table.**
Stratton and Millikan, Experiment 40, a.

Plot the Field of Force (1) for a single pole, (2) for two unlike poles, and (3) for two like poles. Make copies of these diagrams in your note-book on a reduced scale.

403. Magnetic Field of Force with a Compass.
Ames and Bliss, Experiment 63.

404. Comparison of Magnetic Fields by the Method of Vibrations.
Ames and Bliss, Experiment 65.

405. Strength of a Magnetic Field with an Earth Inductor.
Stewart and Gee, Volume II, Lesson LXXI.

406. Comparison of Magnetic Fields with the Bismuth Spiral.

***407. Distribution of Magnetism in a Magnet by the Method of Vibrations.**
Sabine, Experiment 49.

408. Distribution of Magnetism by the Test Nail Method.
Stewart and Gee, Volume II, Lesson XIII.

409. Distribution of Magnetism with the Ballistic Galvanometer.
Stewart and Gee. Volume II, Lesson LXXII.

411. Temperature Coefficient of a Magnet.
Kohlrausch, §62 A.

412. Permeability with the Magnetometer.
Henderson, §§ 294–301.

413. Permeability with the Ballistic Galvanometer.
Henderson, §§302–311.

415. **Determination of the Magnetism in a Bar in Absolute Measure.**

Kohlrausch, §62.

*416. **Determination of H with the Magnetic Pendulum and the Magnetometer.**

Sabine, Experiments 50 and 51.

417. **Determination of H with the Tangent Galvanometer and the Copper Voltameter.**

Sabine, Experiment 54.

418. **Determination of H with the Tangent Galvanometer and the Water Voltameter.**

Ames and Bliss, Experiment 75.

Instead of determining the Galvanometer Constant G, compute this quantity from the number of turns and mean diameter of its coil, and determine H.

421. **Magnetic Dip with the Dip Circle.**

Ames and Bliss, Experiment 64.

*422. **Magnetic Dip with the Earth Inductor.**

Ames and Bliss, Experiment 78.

*424. **Measurement of Current with the Tangent Galvanometer.**

Sabine, Experiment 53.

425. **Measurement of Current with the Helmholtz Tangent Galvanometer.**

Henderson, §§142, 143.

426. **Measurement of Current with the Sine Galvanometer.**

Henderson, §§144, 145.

*430. **Equipotential Lines and Lines of Flow.**

Sabine, Experiment 55.

431. **Magnetic Field of Force due to a Circular Current.**

Stewart and Gee, Volume II, Lesson LVI.

432. Figure of Merit of a Galvanometer.

Stewart and Gee, Volume II, Lesson XVIII.

*433. Resistance with a Wheatstone Bridge of the Slide Wire Form.

Sabine, Experiment 57.

Measure with this instrument the resistances of three coils of wire. Having measured the resistance of each coil separately, measure the resistance of two in series, of three in series, of two in parallel and of three in parallel. Do your results confirm the laws for the resistance of conductors connected in series, and in parallel? For a statement of these laws see Hastings and Beach, §390.

*434. Resistance with a Wheatstone Bridge of the Box Form (Postoffice Box).

Sabine, Experiment 58.

Measure with this instrument the resistances of three coils of wire. Having measured the resistance of each coil separately, measure the resistance of two in series, of three in series, of two in parallel and of three in parallel. Do your results confirm the laws for the resistance of conductors connected in series, and in parallel? For a statement of these laws see Hastings and Beach, §390.

437. Resistance of a Galvanometer by Thomson's Method.

Stewart and Gee, Volume II, Lesson XXV.

438. Resistance with a Tangent Galvanometer.

Miller, §217.

*441. Resistance of a Voltaic Cell by Ohm's Method.

Sabine, Experiment 63.

442. Resistance of a Voltaic Cell by Thomson's Method.

Stewart and Gee, Volume II, Lesson XXXV.

*443. Resistance of a Voltaic Cell by Mance's Method.

Sabine, Experiment 64.

444. Resistance of a Voltaic Cell by Beetz's Method.

Stewart and Gee, Volume II, Lesson XXXVIII.

445. **Resistance of a Voltaic Cell by the Condenser Method.**
Henderson, §§86–88.

448. **Temperature Coefficient of a Voltaic Cell.**
Henderson, §196.

450. **High Resistance with a Galvanometer.**
Stewart and Gee, Volume II, Lesson XXXIII.

451. **High Resistance with an Electrometer.**
Henderson, §73.

*453. **Specific Resistance of Metals.**
Sabine, Experiment 59.

In the case of a wire, its cross-section can best be determined by measuring its diameter with a micrometer guage.

*454. **Temperature Coefficient of Resistance.**
Sabine, Experiment 60.

455. **Specific Resistance of Solutions by Horsford's Method.**
Stewart and Gee, Volume II, Lesson XXXV, Horsford's Method.

*456. **Specific Resistance of Solutions by Kohlrausch's Method.**
Miller, Lesson CXXXII, §§231, 232.

Determine the Specific Resistance, in the manner described in the reference, of 5, 10, 15, 20 and 25 per cent solutions of Copper Sulphate.

With the results, plot a curve showing the variation of Specific Resistance with concentration. Take concentrations for abscissas and Specific Resistances for ordinates.

457. **Specific Resistance of Solutions by Mance's Method using the Electrodynamometer.**
Stewart and Gee, Volume II, §80.

*459. **Absolute Measurement of Resistance with the Calorimeter.**
Sabine, Experiment 69.

460. **Absolute Measurement of Resistance with the Earth Inductor.**
Kohlrausch, Experiment 82, II.

*462. Electromotive Force of a Voltaic Cell by Ohm's Method.

Sabine, Experiment 65.

The values of the current must be calculated from the readings of the Tangent Galvanometer as explained in Experiment 53, Sabine. Assume that $H = .206$, as this is the value found for the Horizontal Component of the Earth's Magnetic Field in the neighborhood of the University of Cincinnati by the United States Magnetic Survey.

463. Electromotive Force of a Voltaic Cell by Wiedemann's Method.

Sabine, Experiment 66.

464. Electromotive Force of a Voltaic Cell by the High Resistance Method.

Ames and Bliss, Experiment 73.

465. Electromotive Force of a Voltaic Cell with a Ballistic Galvanometer and a Condenser.

Ames and Bliss, Experiment 74.

466. Electromotive Force of a Voltaic Cell with a Potentiometer.

Henderson, §219.

467. Electromotive Force of a Voltaic Cell with a Quadrant Electrometer.

Miller, Experiment CXLIII, §254.

469. Construction of a Paraffin Paper Condenser.

Stewart and Gee, Volume II, Appendix F, §6.

*471. Capacity of a Condenser with a Ballistic Galvanometer.

Miller, Experiment CXLVIII, §§262–264.

Determine by this method the capacity of a condenser, by comparing it with a standard.

472. Capacity of a Condenser by the Electrometer Method.

Henderson, §250.

473. Capacity of a Condenser by the Method of Mixtures.

Stewart and Gee, Volume II, Lesson LXXX.

474. Capacity of a Condenser by the Bridge Method using a Direct Current.

Stewart and Gee, Volume II, Lesson LXXIX.

475. Capacity of a Condenser by the Bridge Method using an Alternating Current.

This experiment is to be conducted in the manner of the preceding experiment except that a telephone takes the place of the galvanometer, and a source of alternating current the place of the battery. The balancing resistances should be non-inductive, and the condenser leads as short as possible. The variable resistance must be adjusted until the sound in the telephone is reduced to a minimum.

479. The Dielectric Constant for Solids.

Henderson, §254.

The Dielectric Constant was formerly known as the Specific Inductive Capacity, and now, generally, as the Permittivity.

480. The Dielectric Constant for Liquids.

Henderson, §264.

482. Self Inductance by Rayleigh's Method.

Stewart and Gee, Volume II, Lesson LXXII.

483. Self Inductance by Maxwell's Method.

Henderson, §327.

484. Relative Measurement of Self Inductance with the Galvanometer.

Stewart and Gee, Volume II, Lesson LXXIV.

485. Relative Measurement of Self Inductance with an Alternating Current and a Telephone.

This experiment is to be performed in the manner of the preceding, except that a telephone takes the place of the galvanometer, and a source of alternating current, the place of the battery.

487. Mutual Inductance of Two Coils.

Stewart and Gee, Volume II, Lesson LXXV.

488. Intensity of an Alternating Current with the Absolute Electrodynometer.

Henderson, §§148, 149.

489. Intensity of an Alternating Current with the Current Balance.

Henderson, §§151–157.

490. Intensity of an Alternating Current with the Sieman's Electrodynometer.

Henderson, §§174–177.

491. Intensity of an Alternating Current with a Hot Wire Ammeter.

*493. Frequency of an Alternating Current with a Kundt's Tube and a Telephone.

494. Frequency of an Alternating Current by the Method of Beats.

495. Thermoelectric Force.

Sabine, Experiment 70.

*496. Electrochemical Equivalent of Copper.

Ames and Bliss, Experiment 76.

Read the reference carefully, but instead of determining G or H, determine the value of the Electrochemical Equivalent of Copper. The current passing through the Voltameter may be calculated from the reading of the Galvanometer, and from the number of turns and mean diameter of its coil. (See Sabine, Experiment 53). H in Cincinnati may be taken equal to .206. If a current *i*, flowing for a time *t*, deposits a mass *m* of copper, the Electrochemical Equivalent ϵ is given by the formula

$$\epsilon = \frac{m}{i\,t}$$

*497. Electrochemical Equivalent of Hydrogen.

Ames and Bliss, Experiment 75.

Read the reference carefully but instead of determining the galvanometer constant determine the value of the Electrochemical Equivalent of Hydrogen. The instructions for the preceding experiment (No. 496) hold for this, if "hydrogen" is substituted for "copper".

*498. The Mechanical Equivalent of Heat by the Heating Effect of a Current.

Ames and Bliss, Experiment 77.

Set up the apparatus as instructed in the reference, omitting however the Voltameter as the current can be measured with sufficient accuracy by the Tangent Galvanometer. If the value of H in the Laboratory has not been determined by the student by a previous experiment it may be taken equal to .206 as this is the value obtained by the United States Magnetic Survey in the neighborhood of the University of Cincinnati.

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